APPLICATION OF LANDSLIDE POSSIBILITY INDEX (LPI) SYSTEM ON ROCK SLOPES OF AL-SALMAN DEPRESSION, SOUTHWEST SAMAWA REGION, SOUTH IRAQ

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ABSTRACT

Landslide probability along the rock slopes and their hazards along the edges of Al-Salman Depression, 130 Km southwest of Samawa city, south Iraq was evaluated with Landslide Possibility Index System (LPI). The application of this system is based on field observations and measurements only, by considering ten characteristic features of the slopes and their rock forming.

Only four sites of rock slopes were studied along the edges of Al-Salman Depression, where some rock slopes failures have occurred. The four studied sites comprise the rock slopes of exposures of Dammam Formation (Middle Eocene), which consists of alternations of white, grey and yellowish grey Nummulitic limestone. They are strong (rock material strength between 50 – 100 MPa), moderately weathered, medium to very thickly bedded and widely to very widely spaced joints. The joints apertures range between (0 – 30) cm, with tough and moderately weathered surfaces. The filling materials are soft, clayey and silty sand.

The results of LPI calculations showed that the sites 1, 2 and 3 are of Very Low LPI values, whereas the site-4 has Low LPI value, because the slope height factor was estimated as high. Accordingly, the studied rock slopes in sites 1, 2 and 3 have Low Hazard categories, whereas the site-4 has Moderate Hazard category.

تطبيق نظام دليل احتمالية الانزلاقات الأرضية في المنحدرات الصخرية لمنخفض السلمان، جنوب غرب السماوة، جنوب العراق

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المستخلص

تم تقييم إمكانية حدوث الانزلاقات الأرضية على المنحدرات الصخرية على جروف منخفض السلمان الذي يبعد 130 كم جنوب غرب مدينة السماوة، جنوب العراق، من حساب دليل إمكانية (احتمالية) الانزلاقات الأرضية (LPI). استخدم هذا النظام لسهولة وسرعة إنجازه وبإمكانيات بسيطة. يمكن تحقيق هذا النظام بالمشاهدات والقياسات الحقلية فقط ولعشرة عوامل لخصائص المنحدر والصخور المكونة له.

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تم دراسة أربعة مواقع فقط لمنحدرات صخرية حدث فيها انزلاق، على جروف منخفض السلمان. هذه المواقع الأربعة تتضمن منحدرات لمكاشف صخور العضو الأوسط لتكوين الدمام (الإيوسين الأوسط)، والمتكونة من تعاقبات صخور بيضاء ورمادية ورمادية مصفرة من أحجار الكلس النيوميوليتية والطباشيرية أحيانا. هذه الصخور قوية (ذات مقاومة إنضغاطية بين 50 – 100 ميگا باسكال)، متوسطة التجوية، متوسطة التطبق الى سميكة جدا ومتأثرة بمجموعتين من الفواصل ذات الفسحات البينية الواسعة الى الواسعة جدا وفتحات الفواصل بين (0 – 30) سم وأسطح الفواصل قوية ومتوسطة التجوية. المواد المالئة للفواصل هي مواد رخوة تتكون من رمل غريني وطيني.

بينت نتائج حساب دليل إمكانية الانزلاقات الأرضية إن كل من المواقع 1 و 2 و 3 ذات قيم واطئة جدا (Very Low LPI) ولكن الموقع-4 ذو قيمة واطئة (Low LPI)، وعلى هذا الأساس تكون المنحدرات الصخرية في المواقع 1 و 2 و 3 ذات خطورة واطئة (Low Hazard) والمنحدر الصخري في الموقع-4 ذو خطورة متوسطة (Moderate Hazard).

INTRODUCTION

Four sites were studied in detail in an attempt to assess the stability of the rock slopes on the edges of Al-Salman Depression. These four sites form rock slopes of exposures of the Middle Member of Dammam Formation (Middle Eocene).

Al-Salman Depression in which the study was carried out, is 130 Km southwest of Samawa city, it is bounded by latitude 30° 30' 00" to 30° 37' 30" N, and longitude 44° 30' 00" to 44° 37' 30" E (Fig.1).

Geologically, the studied rock slopes form the exposures of Dammam Formation (Middle Eocene), which is divided into three members, (Al-Mubarak and Amin, 1983). The exposed rocks belonged to the Middle Member and consist of an alternations of white, yellowish grey and grey limestone, fine crystalline, occasionally Nummulitic and chalky. The field inspection showed that these rocks are strong, with rock material strength between (50 – 100) MPa, moderately weathered, medium to very thickly bedded and with widely to very widely spaced joints.

Tectonically, the studied area is located within the Inner Platform, at about 120 Km southwest of Abu Jir Fault Zone, which represents the eastern boundary between the Stable and Unstable Shelf of the Arabian Platform, (Fouad, 2007).

Geomorphologically, Al-Salman Depression represents a karst landform developed by the dissolution of the carbonate rocks of the Middle Member of Dammam Formation (Middle Eocene) by the infiltration of the surface water into the fractures and joints, and/ or the underlying anhydrite rocks of Rus Formation (Early Eocene) by ground water (Al-Mubarak and Amin, 1983).

This shallow, gentle and closed karst is of oval shape with axis extends N40E and 20 Km long and 4.5, 6.5 and 10 Km width in south, north and central parts, respectively, whereas the depth ranges from (5 – 35) m.

The lowest elevation is 200 m (a.s.l) south of Al-Salman city and the highest elevation is 281 m (a.s.l) south Al-Salman Depression and east of Faidhat Al-Sa'a. The edges of this depression consist of rock slopes range (10 ─ 35) m in heights.

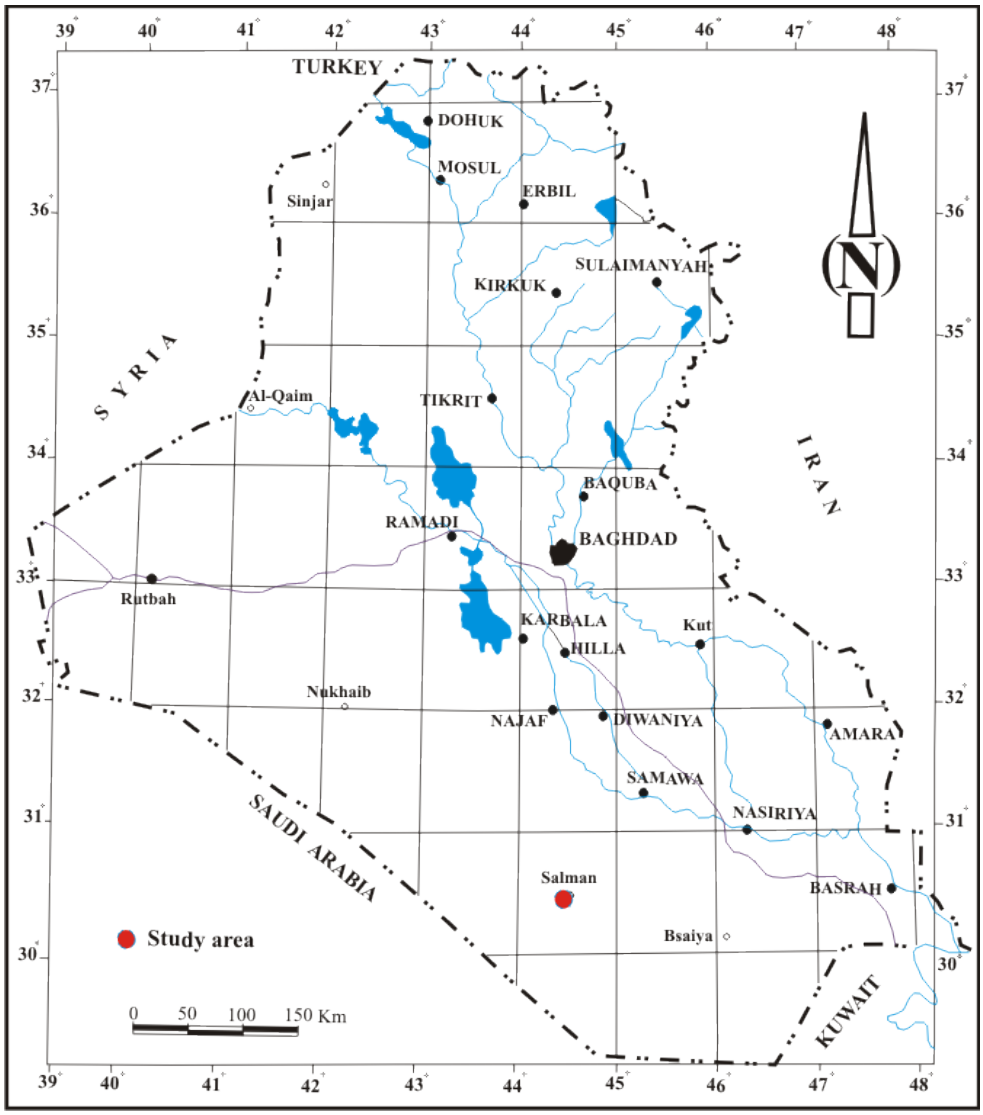

Fig.1: Location map of Al-Salman Depression

PREVIOUS WORKS

Different previous geological efforts were executed within the Iraqi Southern Desert. Extensive field works have been executed in the Southern Desert by many of the GEOSURV geologists. In the previous executed works all of the aspects of geology have been studied including: geomorphology, stratigraphy, structure, hydrogeology and even geotechnical investigations.

- Ma'ala (2009) stated that the Iraqi Southern Desert forms relatively flat terrain, sloping gently towards east and northeast. The present surface of the Southern Desert is attributed to rejuvenated plateau marked by 24 landform assemblages, which is the product of the former various denudational and depositional processes in two continental phases of destruction and construction processes.
- Jassim and Al-Jiburi (2009) reviewed the stratigraphic succession of the Iraqi Southern Desert and divided the exposed rock formations and age wise, into Paleogene (Umm Er Radhuma and Dammam formations) and Neogene (Euphrates, Ghar, Nfayil, Dibdibba and Zahra formations) Epochs.

– Al-Jiburi and Al-Basrawi (2009) denoted that rainfall is the main source of water in the Southern Desert. The drainage system is internal, with most of the surface water percolating to underground through permeable strata, fractures, fissures and karst cavities. Groundwater movement is from recharge areas in the south and southwest towards the main discharge zone to the east and northeast along Euphrates River, Hor Al-Hammar and Shatt Al-Arab.
– Kadhum *et al*. (2011) carried out geological investigation for mineral occurrences and industrial rocks in Muthana Governorate. They pointed out some locations with raw materials suitable for industrial purposes like, limestone for cement, dolomitic limestone for glass industries and clays for cement and brick industries.
– Sissakian *et al*. (2012) studied the genesis and age determination of Al-Salman Depression. They mentioned that the presence of the sediments of Zahra Formation (Pliocene – Pleistocene) in the Salman Depression indicates Pliocene and most probably Late Miocene age for the depression that has developed due to collapse and karstification, which is a still active process.
– Arteen and Ameer (2001) carried out the only existing previous geotechnical study for the substitutes of marble in Salman area. Their investigation indicated the presence of three economic layers within Shawiya Unit of the Middle Member of Dammam Formation. These economic layers are of accepted technical specifications for marble according to ASTM-C-503-67 (Standard Specification for Dimension Limestone) (1973) in Arteen and Ameer (2001).

METHODOLOGY

There are a series of classification systems used for rock slope stability analyses. One of them is the "Landslide Possibility Index" system (Bejerman, 1994). This system can be easily performed, and does not need laboratory tests and depends on the estimation of field measurements only. This estimation system considers characteristic features of the slope estimated in the field and then applied in the chart included in Bejerman (1995).

The Landslide Possibility Index system (LPI) was used to estimate the stability of the rock slopes of Al-Salman Depression, because it depends on the field measurements for the slope circumstances, discontinuities characteristics and climate conditions, in addition to, it is easy and does not need expensive laboratory tests.

The landslide hazard consequence associated or resulted from these rock slopes failures were categorized according to "Landslide Possibility Index" system values (Bejerman, 1998).

▪ Rock Slope Stability Analyses According to Landslide Possibility Index (LPI):

According to the (LPI) method, the hazard degree of slopes is determined by the value of Landslide Possibility Index (LPI). This value depends on 10 parameters, as listed in Table (1). There is some estimation for the value of each parameter, which is determined for each slope according to the geological, structural, hydrological and geomorphological conditions, at the studied site. The sum of estimations represents the LPI value (Table 1).

The assessment of the LPI category neither establishes the quantity and time for the block to slide nor identifies the stabilization method. The main objective is to evaluate the possibility and to indicate the need for a detailed study, regarding the stability of certain rock slopes with respect to others that present fewer tendencies to the slide.

Table 1: Landslide Possibility Index (LPI) estimation (Bejerman, 1994)

1- Slope height	**Estimation**	**2- Slope angle**	**Estimation**
(1 – 8) m	1	< 15°	0
(9 – 15) m	2	(15 – 30)°	1
(16 – 25)m	3	(30 – 45)°	2
(26 – 35) m	4	(45 – 60)°	3
> 35 m	5	> 60°	4
3- Grade of fracture	**Estimation**	**4- Grade of weathering**	**Estimation**
		Fresh	0
Sound	0	Slight	1
Moderately Fractured	1	Moderate	2
Highly Fractured	2	High	3
Completely Fractured	3	Complete	4
		Residual soil	5
5- Gradient of the discontinuities	**Estimation**	**6- Spacing of the discontinuities**	**Estimation**
< 15°	0	> 3 m	0
(15 – 30)°	1	(1 – 3) m	1
(30 – 45)°	2	(0.3 – 1) m	2
(45 – 60)°	3	(0.05 – 0.3) m	3
> 60°	4	< 0.05 m	4
7- Orientation of the discontinuities	**Estimation**	**8- Vegetation cover**	**Estimation**
Favorable	0	Void < 20%	0
Unfavorable	4	Scarce (20 – 60) %	1
		Abundant > 60%	2
9- Water infiltration	**Estimation**	**10- Previous landslides**	**Estimation**
Inexistent	0		
Scarce	1	Not registered	0
Abundant		Registered (small volume)	1
Permanent	2	Registered (high volume)	2
Seasonal	3		
1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10 =			
I (Small) (0 – 5)	III (Low) (11 – 15)	V (High) (21 – 25)	
II (Very Low) (6 – 10)	IV (Moderate) (16 – 20)	VI (Very High) (> 25)	
The LPI value is obtained by adding the estimation of attributes 1 – 10. If the orientation of the discontinuities is favorable, **subtract** the estimation of gradient.			

▪ Failure Hazard Zonation According to LPI Values

After each factor is quantified, the values obtained are added up to determine the (LPI) for the slope. The criterion for the estimation of the factors was defined in Bejerman (1994). Eventually, the hazard degree of slopes classified into three categories according to this value (Bejerman, 1998) (Table 2).

Table 2: Landslides hazard categories (according to Bejerman, 1994 and 1998)

Landslide Possibility Index			**Hazard Zone**	
Grade	**Category**	**Estimation**		
VI	Very High	> 25	> 25	High Hazard
V	High	21 – 25		
IV	Moderate	16 – 20	(11 – 20)	Moderate Hazard
III	Low	11 – 15		
II	Very Low	6 – 10	< 10	Low Hazard
I	Small	1 – 5		

▪ **Field Description of the Rock Slopes of Al-Salman Depression**

Rock slopes along the edges of Al-Salman Depression were studied in four sites around the depression (Fig.2).

The field inspection of the rock slopes around the Salman Depression showed that the exposed rocks consist of an alternations of white, yellowish grey and grey limestone, fine crystalline, occasionally nummulitic and chalky. They are strong, rock material strength between (50 – 100) MPa, moderately weathered, medium to very thickly bedded and widely to very widely spaced joints. These rocks had been affected by two sets of orthogonal joints, originated by tensile stresses perpendicular to the main compressional stresses due to overburden.

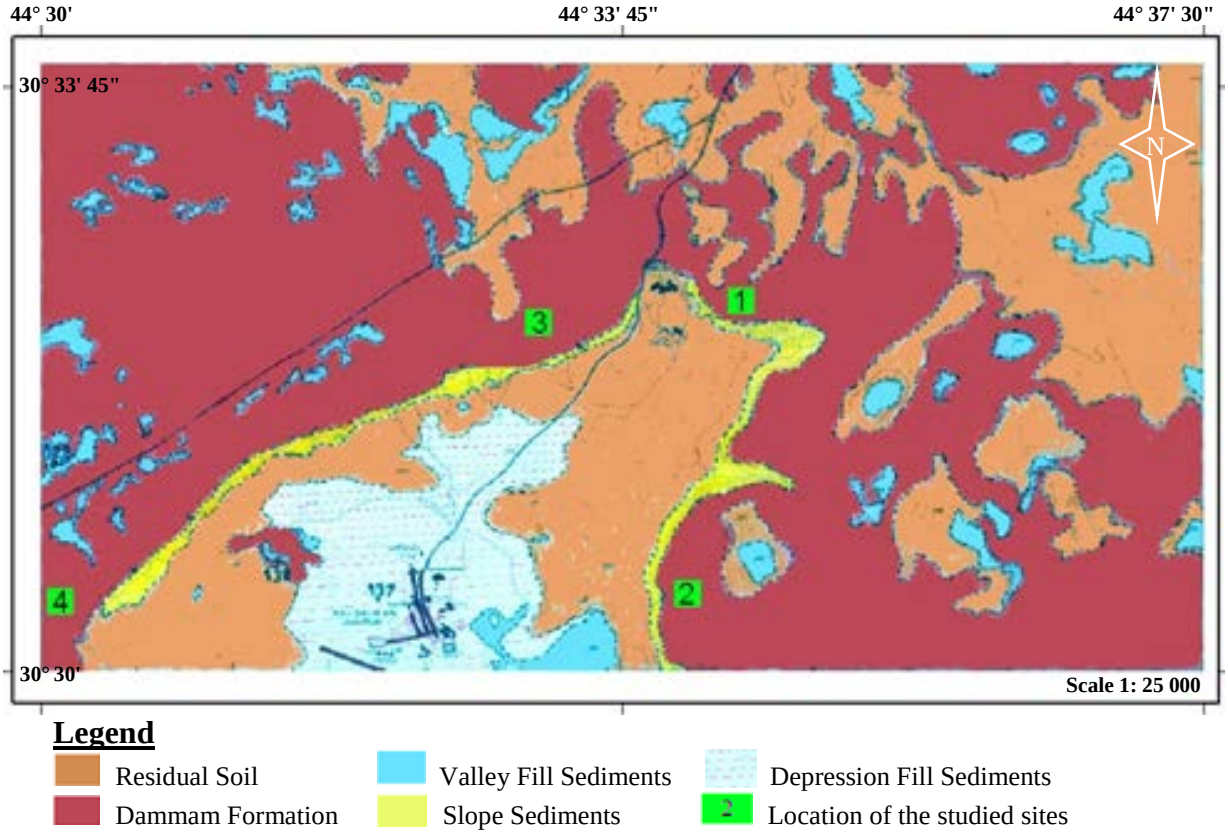

Fig.2: Geological map showing the four studied sites
(after Mahmood *et al*., in press)

ROCK SLOPE STABILITY ANALYSIS OF THE STUDIED AREA

▪ **Site-1**

This site is (9 – 12) m height, gentle slope (15 – 25º) and facing 180º south. It composed of thickly to very thickly bedded (0.5 – 5.0 m) strata of limestone, gently dipping (240/12º) towards the center of the depression (Fig.3). It is slightly weathered and moderately fractured by two sets of vertical joints (180/90º and 252/90º). They are characterized by widely to very widely spaced, moderately weathered and strong surfaces opened with apertures between (0 – 40) mm and the filling materials are soft silty sand. At this slope, the detached rock fragments by mechanical weathering (due to temperature differences and rain water) and fail down slope due to gravity.

Fig.3: Side view of the rock slope of Site-1

- **Site-2**

This site is (17 – 20) m height, the left part of this site has local gentle slope (<15º) and facing 140º SE. It composed of thickly to very thickly bedded (0.5 – 4.0m) limestone, gently dipping (250/13º) towards the center of the depression (Fig.4). It is slightly weathered and moderately fractured by two sets of vertical joints. These two sets of joints are 250/90º and 310/90º. They are characterized by widely to very widely spaced, moderately weathered and strong surfaces opened with apertures between (0 – 60) mm and the filling materials are soft sandy silt.

Fig.4: The frontal view of the rock slope of Site-2

In Fig. (4), note that the strata at the left part of this site has a gentle dip angle towards the depression, due to karstification in which case the strata becomes prone to fail by plane sliding along the bedding planes or toppling due to differential weathering (Fig.5).

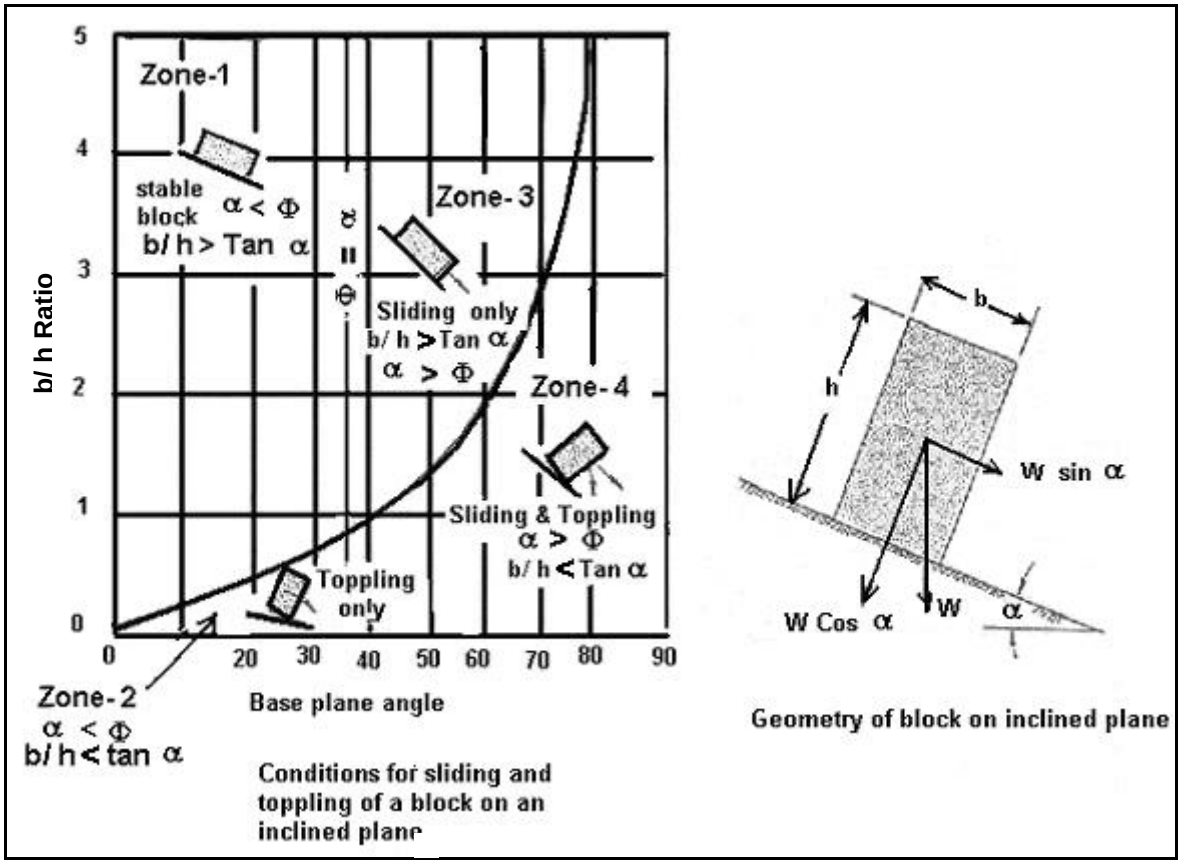

Fig.5: The relationship between toppling and sliding of rock mass along inclined surface (Hoek and Bray, 1981)

- **Site-3**

This site is (20 – 25) m height, gentle slope (155/<15º) and composed of thickly to very thickly bedded (0.5 – 2.5 m) limestone, gently dipping (70/14º) towards the center of the depression (Fig.6). It is slightly weathered and moderately fractured by two sets of vertical joints (215/90º and 290/90º). They are characterized by widely to very widely spaced, moderately weathered and strong surfaces with apertures between (0 – 30) mm and the filling materials are soft sandy silt.

Site-3 demonstrates a gently dipping strata towards the center of Al-Salman Depression, due to karstification that make the rock blocks potentially failed by plane sliding along the bedding planes or toppling due to differential weathering by rain water.

Fig.6: The studied left part of the rock slope of Site-3

- **Site-4**

This site is 33 m height, gentle slope (140/15º – 140/25º) and composed of thickly to very thickly bedded (0.5 – 2.5 m) limestone, gently dipping (70/14º) towards the center of the depression (Fig.7). The rocks is slightly weathered and moderately fractured by two sets of vertical joints and the attitudes of these two sets of joints are 180/90º and 262/90º. They are characterized by widely to very widely spaced, moderately weathered and strong surfaces with apertures between (0 – 30) mm and the filling materials are soft sandy silt.

Figure (7) shows that the rock failures are plane sliding due to undercutting by the seasonal stream water, as shown at the toe of the slope (to the right of the figure) and toppling due to the differential weathering by rain water as shown at the top of the slope.

Fig.7: Side view of the rock slope of Sit-4

- **Landslide Possibility Index of the Rock Slopes of the Studied Area**

The field measurements of the factors that contribute to estimate the landslide possibility index (LPI) on the rock slopes of Al-Salman Depression revealed that the Sites 1, 2 and 3 are of Very Low LPI values, but Site-4 has Low LPI value (Table 4 and Fig.8). Site-4 has relatively higher LPI value than the other sites, because it is relatively high slope height (Fig.9). Eventually, the sites 1, 2 and 3 have Low Hazard categories, whereas site-4 has Moderate Hazard category.

Table 4: The results of LPI calculations of the studied rock slopes

Site No.	**1**	**2**	**3**	**4**
Slope height	2	3	3	5
Slope angle	0	0	0	0
Grade of fractures	1	1	1	1
Grade of weathering	1	1	1	1
Gradient of discontinuities	4	4	4	4
Spacing of discontinuities	0	0	0	0
Orientation of discontinuities	0	0	0	0
Vegetation cover	0	0	0	0
Water infiltration	3	3	3	3
Previous landslide	1	1	1	1
LPI values	12 – 4 = 8	13 – 4 = 9	13 – 4 = 9	15 – 4 = 11
(LPI) category	V.L	V.L	V.L	L
Hazard category	L.H	L.H	L.H	M.H

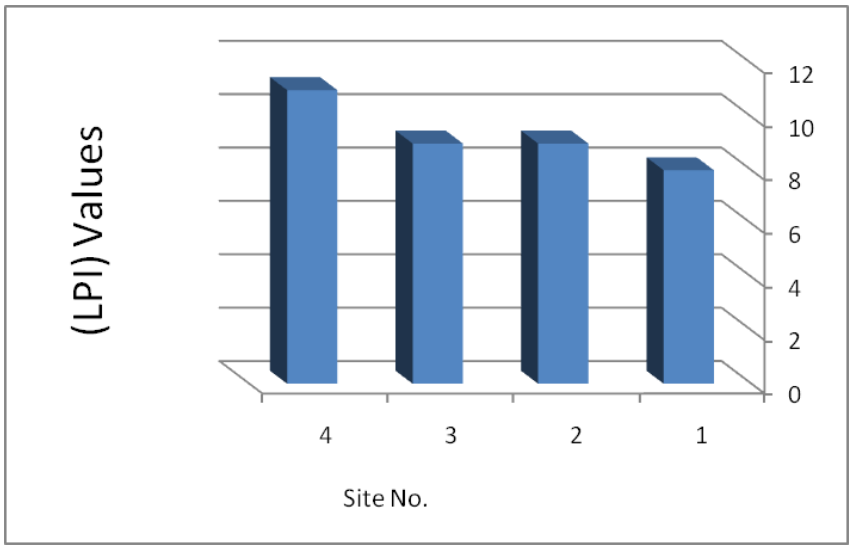

Fig.8: LPI values simulation diagram for the studied four slopes

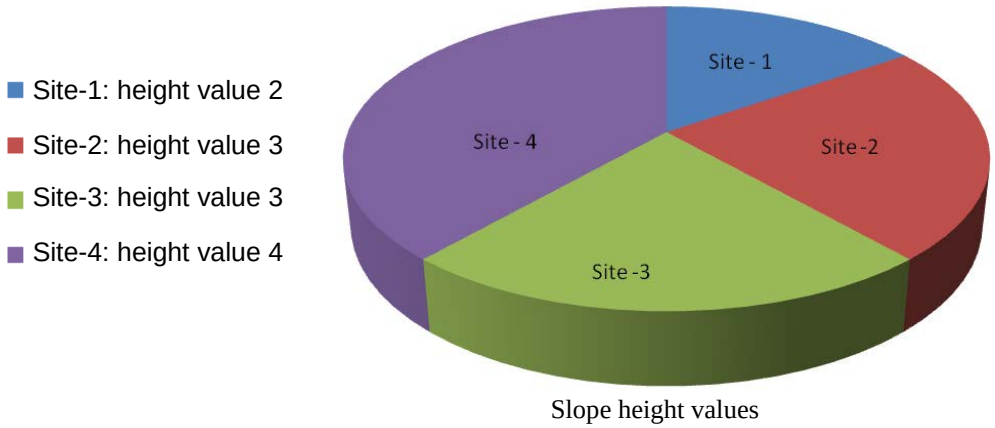

Fig.9: Slope height representation diagram of the studied slopes

CONCLUSIONS

- The rock slopes consist of horizontally dipping strata, where they are the less instable. But, due to the karstification by the groundwater and the under cutting by the seasonal stream water, rock blocks failures were developed as toppling or plane sliding due to gravity.
- The results of the LPI estimations indicated that the rock slopes at Sites 1, 2 and 3 are of Low LPI values, but have Moderate Hazard categories, while Site-4 has Moderate LPI and Moderate Hazard category.
- Site-4 has high LPI value and accordingly has Moderate Hazard, due to relatively the more slope height.

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